Climate Signals in AIRS and IASI data

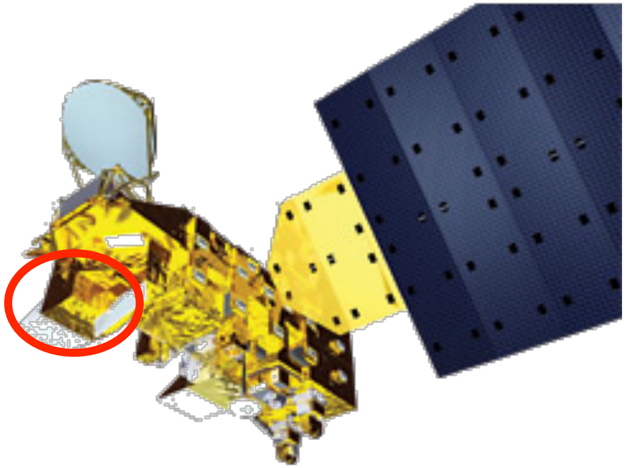
Hartmut H. Aumann and Evan Manning
Jet Propulsion Laboratory, California Institute of Technology

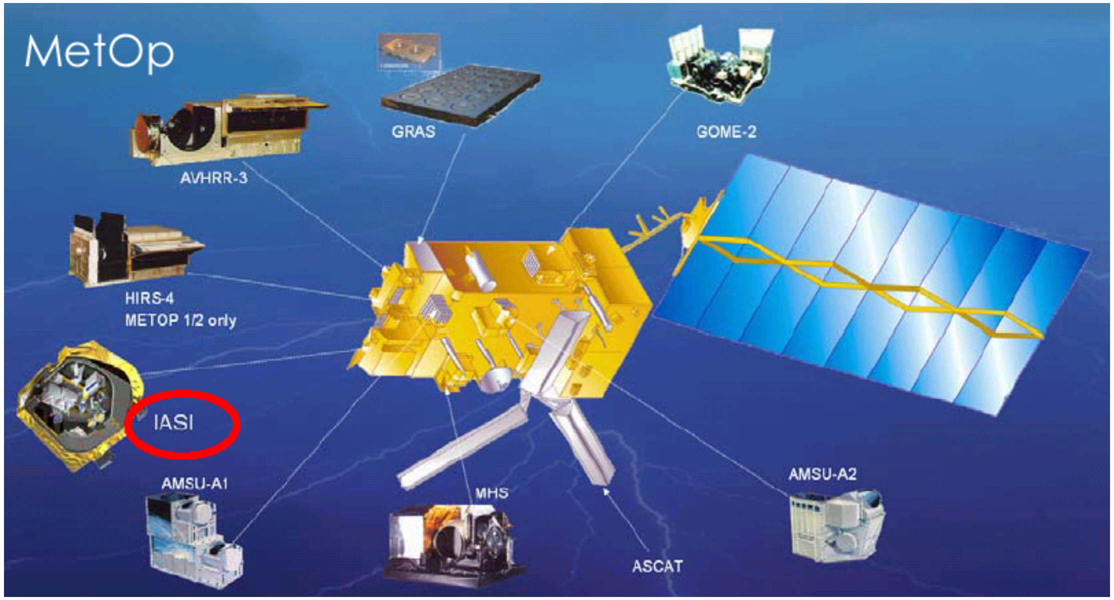
and

Sergio DeSouza-Machado
University of Maryland, Baltimore Campus

EuMetsat 2014, September 23, 2014, Geneva, Switzerland
AIRS Team Meeting, Greenbelt, MD. September 30, 2014

AIRS on EOS Aqua
1:30 PM polar orbit
Launch May 2002
Operational data since September 2002





IASI on MetOp A
9:30 AM polar orbit
Launch October 2006
Operational data since July 2007

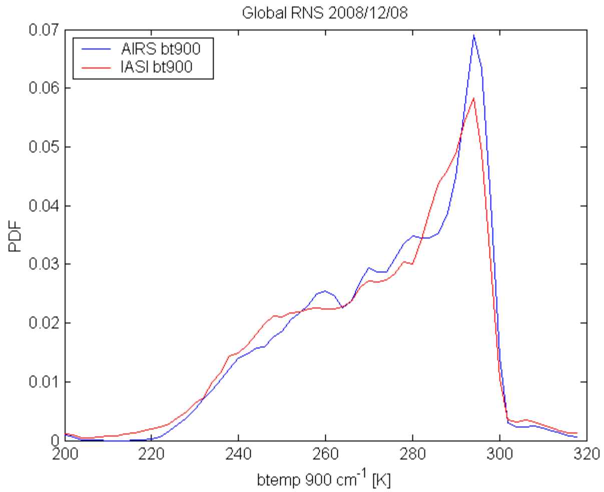
Outline

1. Definitions: Climate, Climate Variability and Climate Change
2. Cloud Effects measured with AIRS and IASI
   - Infrared Cloud Effect
   - Deep Convective Clouds
   - Altostratus Clouds
3. Applications GCM and Climate Models

Climate is defined as the mean state of an observable related to weather.

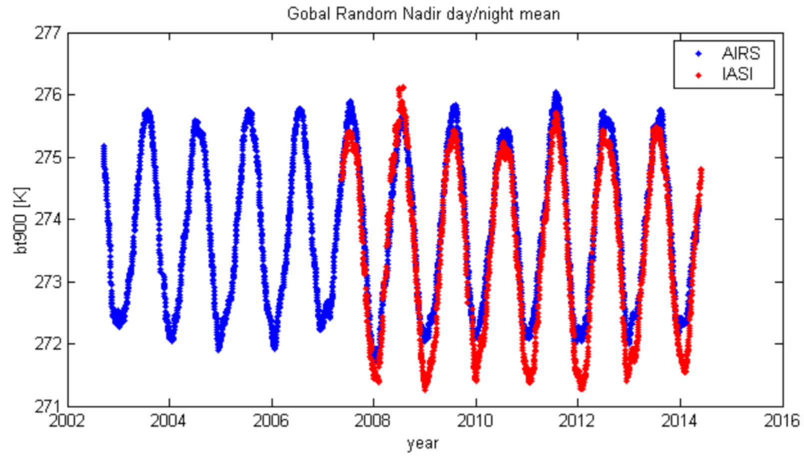
We define climate as the seasonal modulation of an observable. AIRS and IASI both measure parameters related to climate.

Calculate the daily PDF of the RNS for the 900 cm-1 window channel.



PDF of the global observable from one day

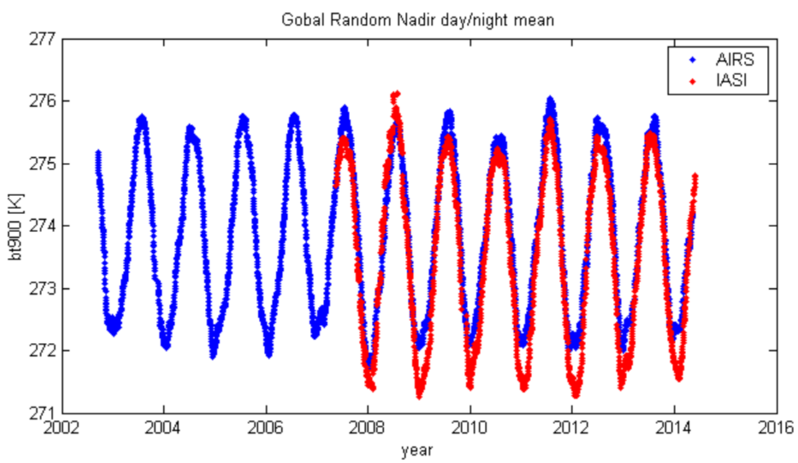
Calculate the daily mean
Generate the time series.



Time series

H. H. Aumann

Climate variability is defined as the decadal (or longer) deviation of a climate parameter from the mean state. This is measured using the anomaly.



Let y(t) be the time series of the daily samples. The seasonal variability can be approximated by a short Fourier expansion which contains only frequencies higher than one year.

$$Y(t) = a_0 + \sum_{n=1}^{12}(a_n \cos 2n\pi t + b_n \sin 2n\pi t) + r(t),$$

r(t) is the residual, which contains signal varying faster than monthly, i.e. mostly noise, and signals with variability on a timescale longer than one year.

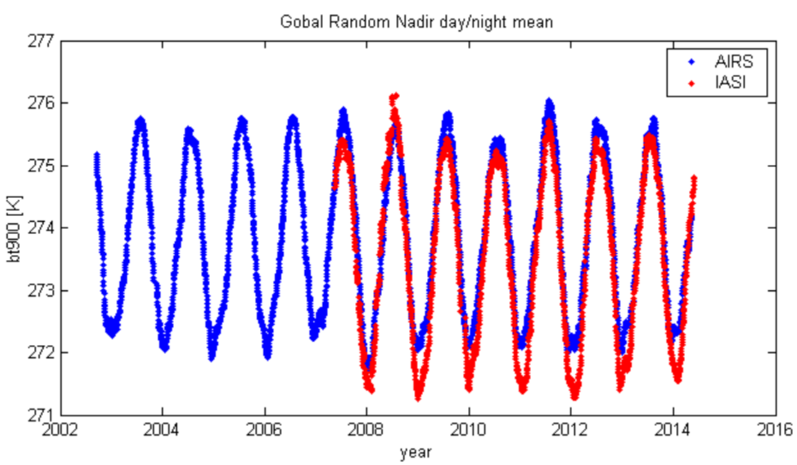
The r(t) time series is the anomaly.
The linear trend in r(t) is the anomaly trend.

The accuracy of the anomaly trend improves as the (length of the data record) $^{3/2}$ provided the data are stable.

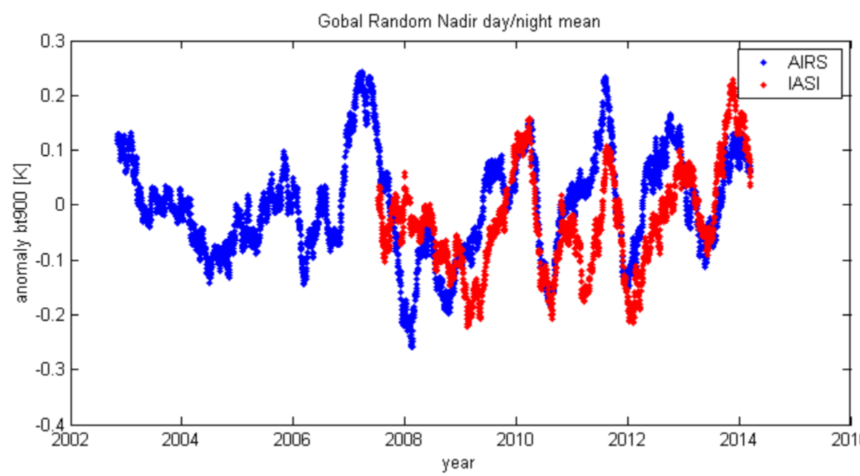
H. H. Aumann

AIRS and IASI anomalies measure variability which transcend differences due to their orbits.

Daily data show the annual seasonal modulation



Subtract the annual seasonal modulation to show the "Anomaly".



Global 0.5K peak-to-peak inter-annual variability limits the interpretation of 12 year trends

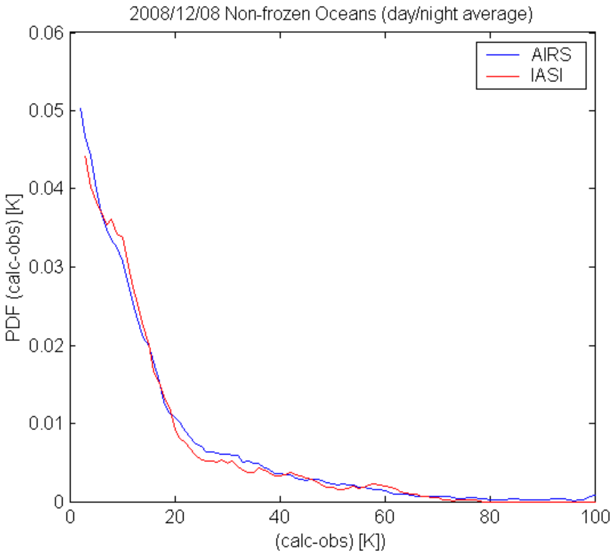
H. H. Aumann JPL

Climate signal related to clouds
AIRS and IASI

1. All cloud infrared opacity
2. Deep Convective Clouds
3. Alto stratus clouds
4. OLR (legacy)

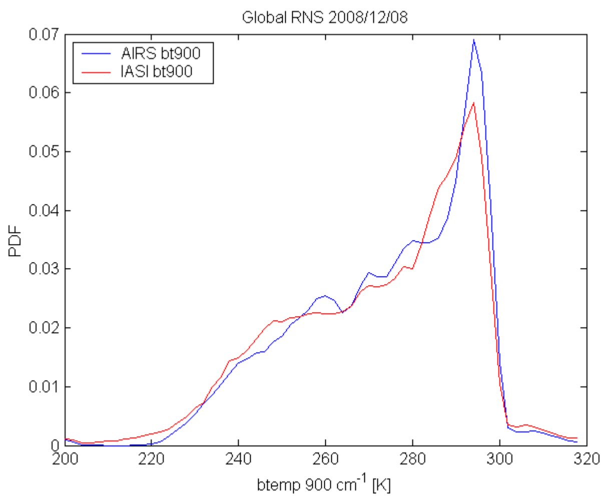
Example 1. Infrared Cloud Effects

Clouds change the signature of the upwelling spectral radiation.
We limit our attention to parameters which are observed by AIRS and IASI and which can be readily calculated from GCM and climate models



1. For the non-frozen oceans calculate the daily mean of (calc-obs). calc = expected bt900 based on the known SST, ignoring clouds. obs = observed bt900.
Under clear conditions (obs-calc) will be zero.

For 2008/12/08
AIRS mean = 12.02K stdev= 15.57K β=0.77
IASI mean = 10.95K stdev= 13.67K β=0.80



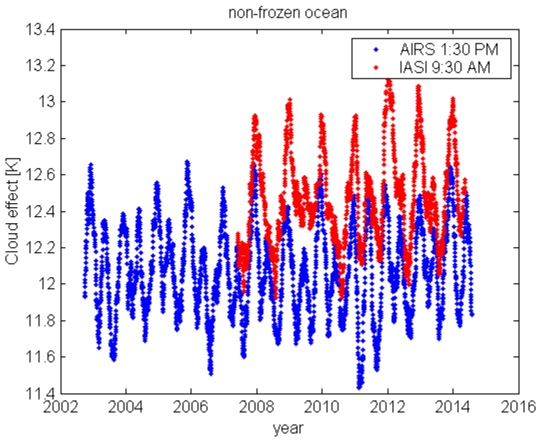
2. For global data use the 10%tile of the daily bt900. This does not require knowledge of the surface temperature.
AIRS = 242.20K
IASI = 244.13K

H. H. Aumann

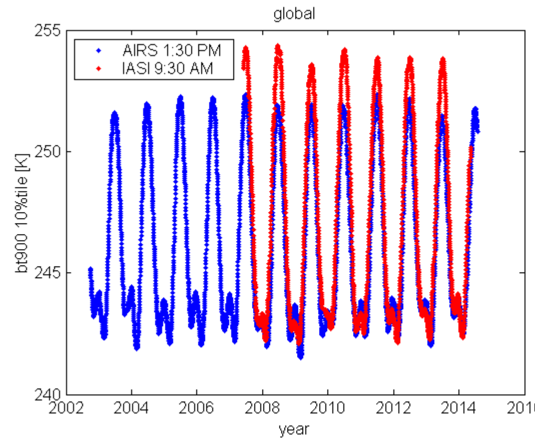
Global cloud effects AIRS and IASI different because of the difference in the diurnal cycle observed from the morning and noon orbits

The cloud effect

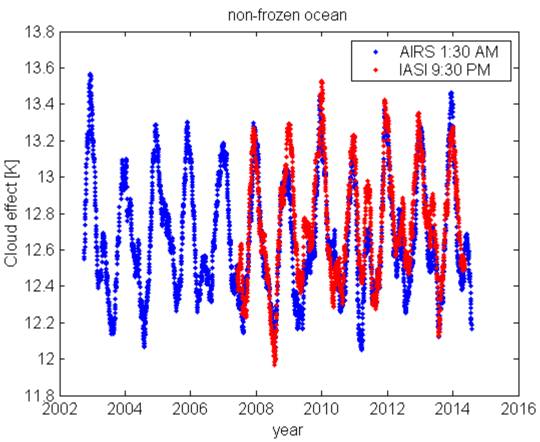
bt900 10%tile



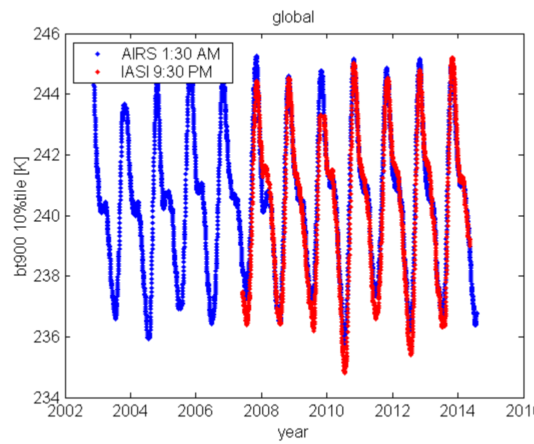
Day non-frozen ocean
AIRS 12.07 K
IASI 12.48 K



Day global
AIRS 246.12 K
IASI 247.30 K



Night non-frozen ocean
AIRS 12.66 K
IASI 12.75 K



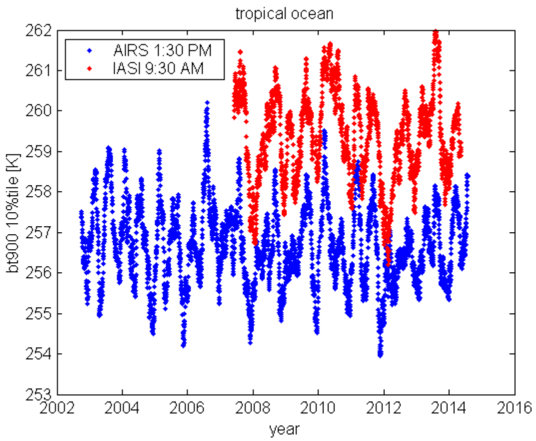
Night global
AIRS 240.43K
IASI 240.19K

The morning (IASI) orbit is less cloudy than the noon (AIRS) orbit.

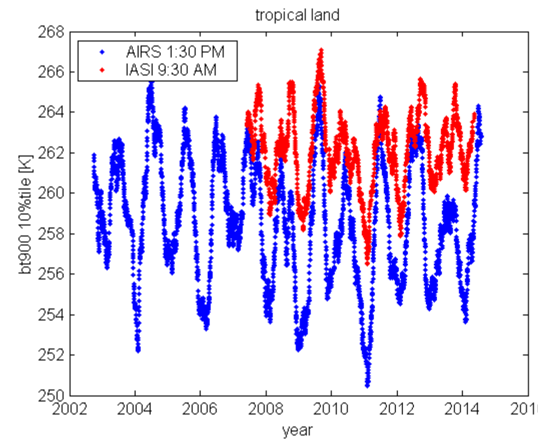
H. H. Aumann

Tropical day/night land/ocean effects AIRS and IASI different because of the difference in the diurnal cycle

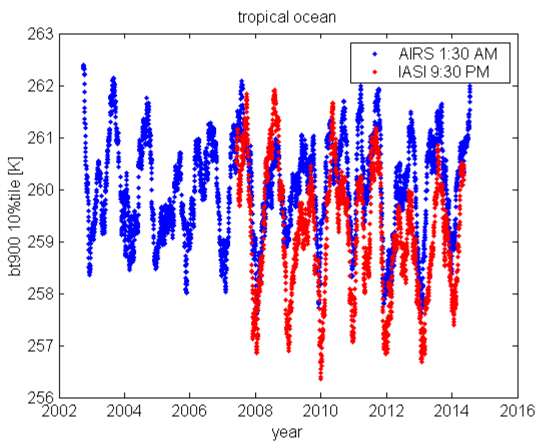
bt900 10%tile for the tropical zone



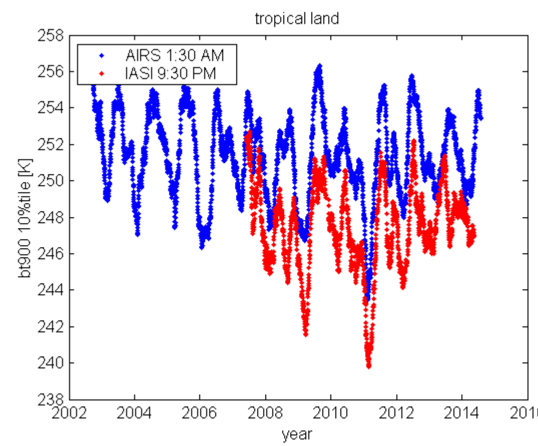
Day tropical ocean
AIRS 256.68 K
IASI 258.36 K
IASI has less clouds in the morning
Delta=1.68K



Day tropical land
AIRS 258.58 K
IASI 262.17K
Delta=3.59 K



Night tropical ocean
AIRS 260.07 K
IASI 259.17 K
Delta=-0.90K



Night tropical land
AIRS 251.38 K
IASI 247.48K
Delta=-3.90 K

H. H. Aumann

Example 2: Deep Convection

Deep Convective Clouds (DCC) are identified as spectra in the tropical zone where the 900 cm-1 brightness temperature is less than 210K

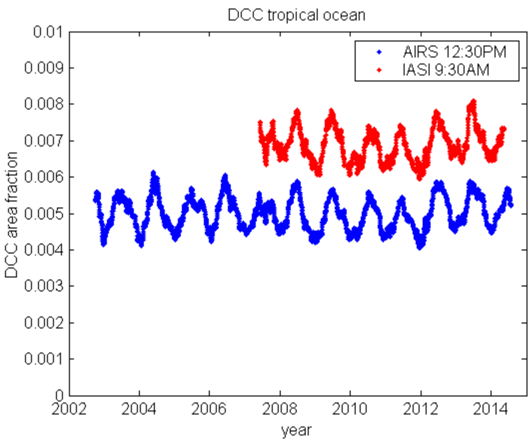
DCC typically cluster on a 100 km and large scale

DCC are used with GOES data to estimate rainfall.

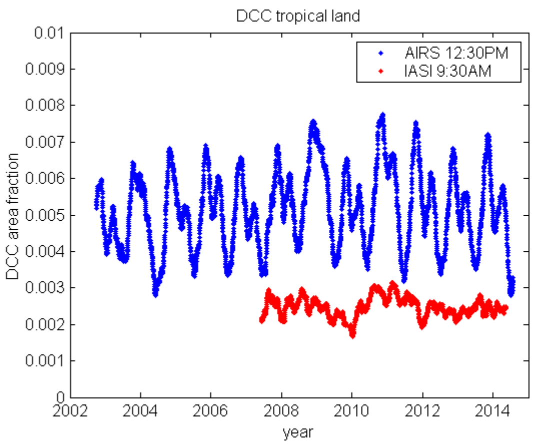
DCC can be considered as proxies for total rainfall

Aumann, H. H., David Gregorich and Sergio M. DeSouza-Machado (2006) "AIRS Observations of Deep Convective Clouds", SPIE Photonics Conference 13-17 August 2006 San Diego, CA, paper 6301-20.
Aumann, Hartmut H., Alexander Ruzmaikin and Joao Teixeira (2008) "Frequency of severe srorms and global warming" *GRL* v.35, L19805, doi:10.1029/2008GRL034562.
Aumann, H.H. , S.G. DeSouza-Machado and A. Behrangi 2011: Deep Convective Clouds at the Tropopause, *Atmos.Chem. Phys*., 11, 1-10, 2011 doi:10.5194/acp-11-1-2011
Aumann H. H. and A. Ruzmaikin , 2013: Frequency of deep convective clouds from ten years of AIRS data, ACP 13, 1-39, doi:10.5194/acpd-13-1-2013

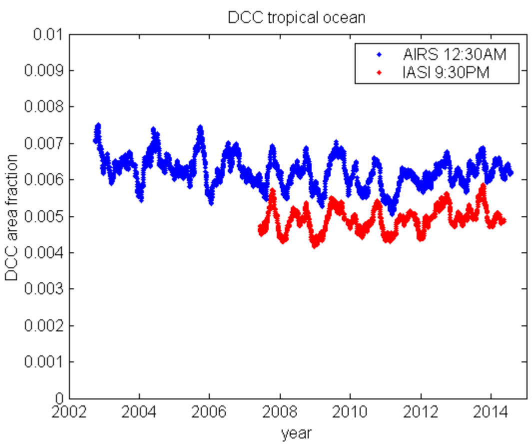
There is an unexpected difference between AIRS and IASI for the frequency of DCC



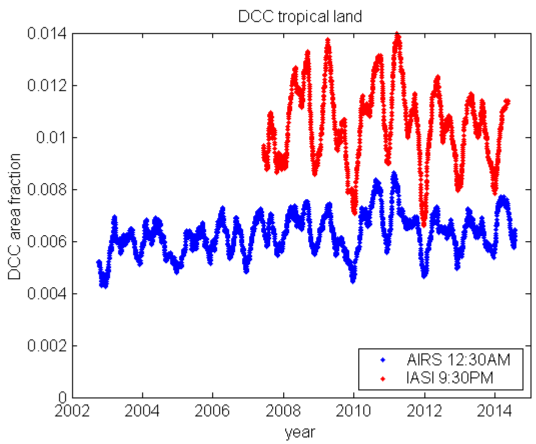
Day tropical ocean
AIRS 0.0050
IASI 0.0069



Day tropical land
AIRS 0.0051
IASI 0.0025



Night tropical ocean
AIRS 0.0062
IASI 0.0049

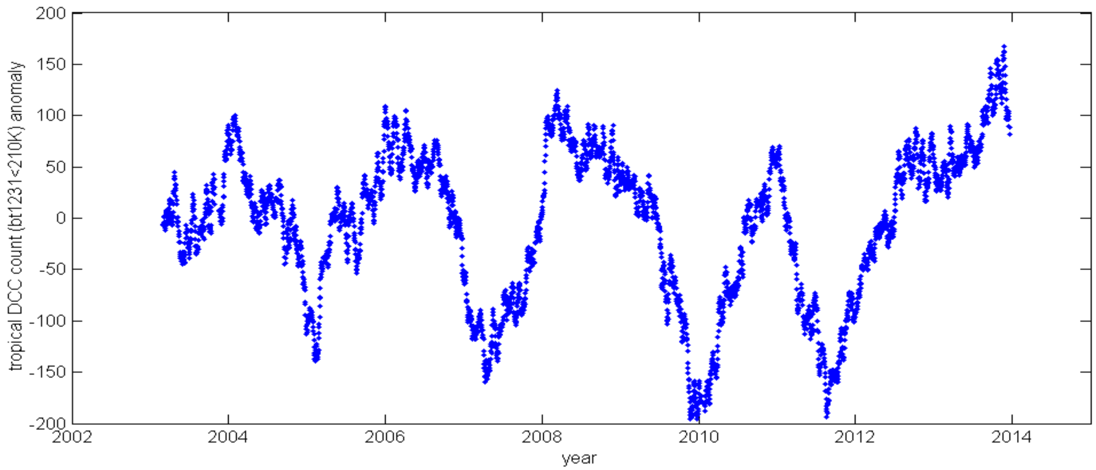


Night tropical land
AIRS 0.0063
IASI 0.0104

The weak diurnal cycle from AIRS is consistent with TRMM
The strong diurnal cycle from IASI is not consistent with TRMM.

H. H. Aumann

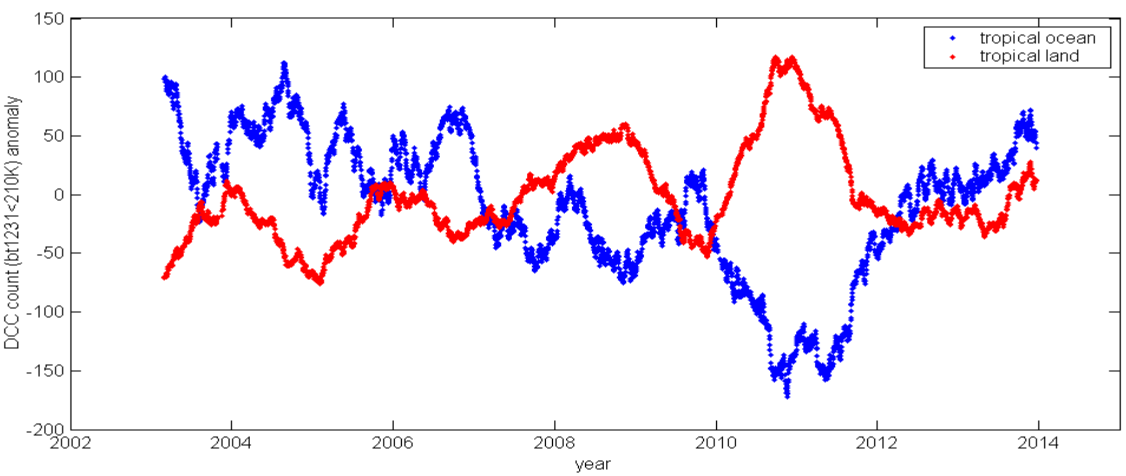
Quasi bi-annual fluctuations of the DCC count are land/ocean anti-correlated.



The DCC anomaly for the tropical zone has a strong bi-annual mode suggestive of ENSO.

The 12 year anomaly trend is zero within the trend uncertainty

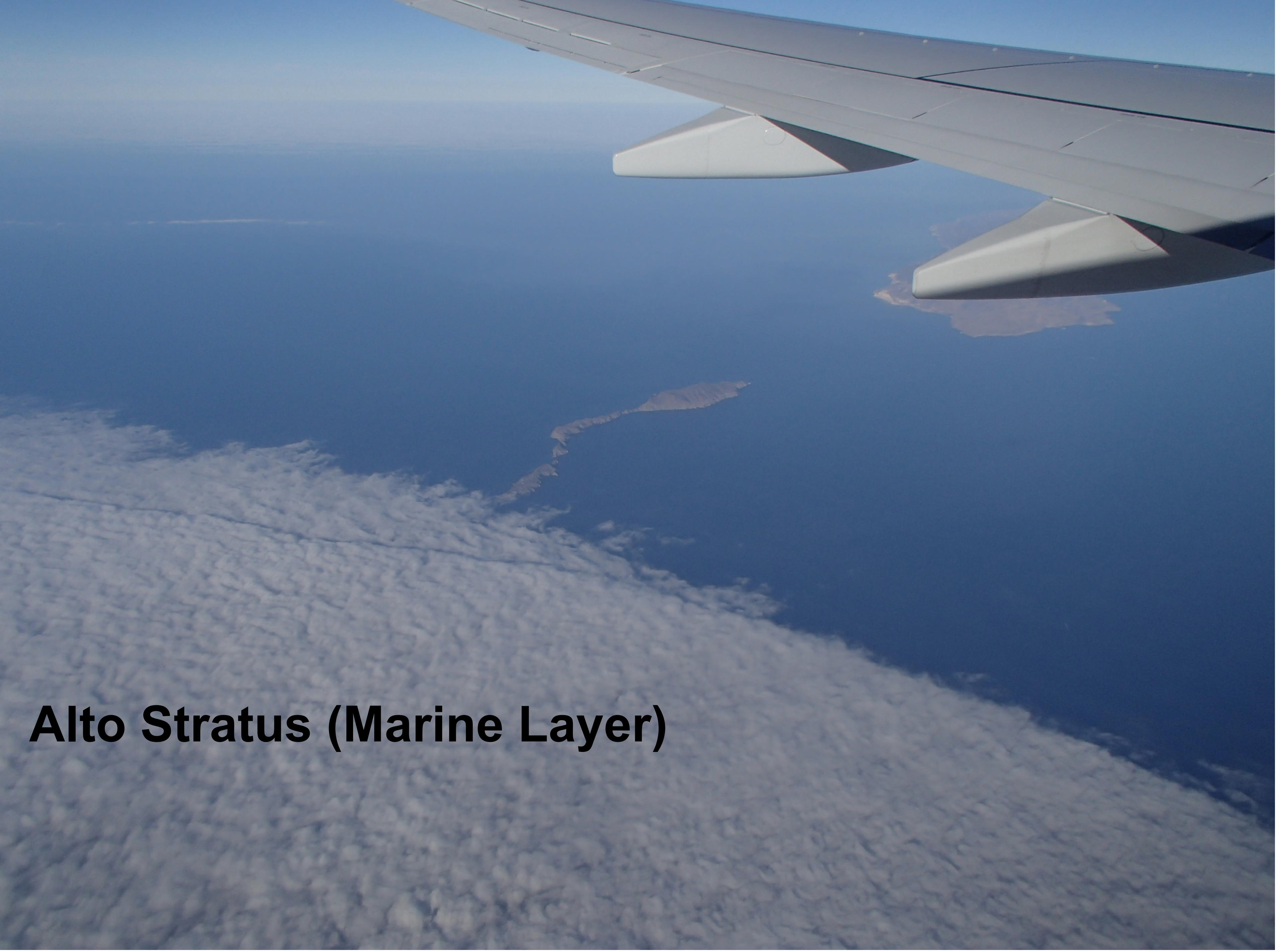
+ 0.051+/- 0.097%/yr



Land and ocean DCC anomalies are anti-correlated

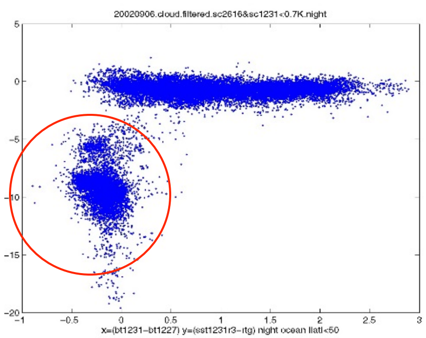
The signature of ENSO is prominent

H. H. Aumann

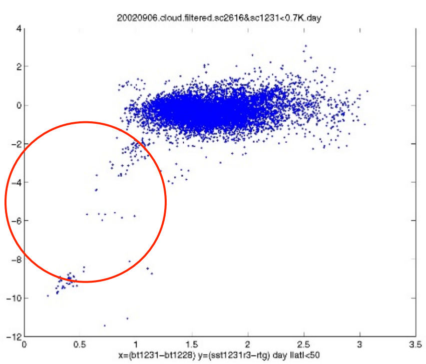

Alto Stratus (Marine Layer)

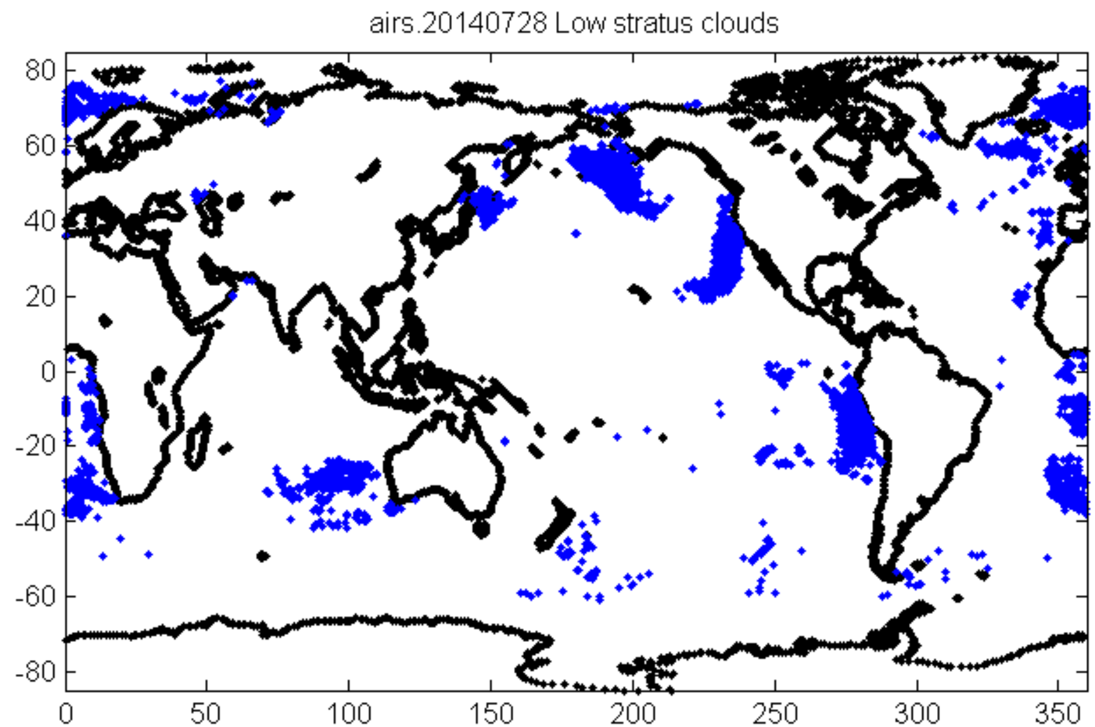
Example 3. Altostratus Clouds
Detected as spatially extremely uniform footprints about 3-10K colder than the known surface temperature.

Most at 1:30 AM



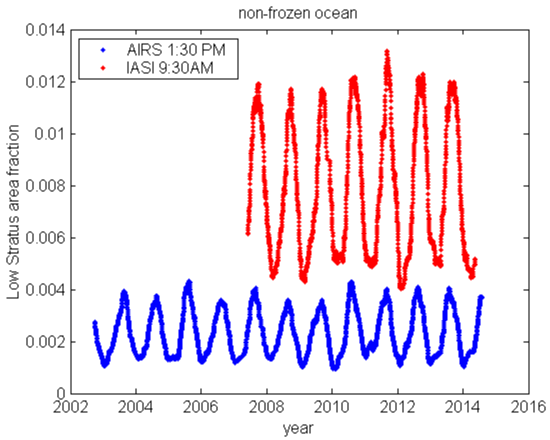
Almost none 1:30 AM





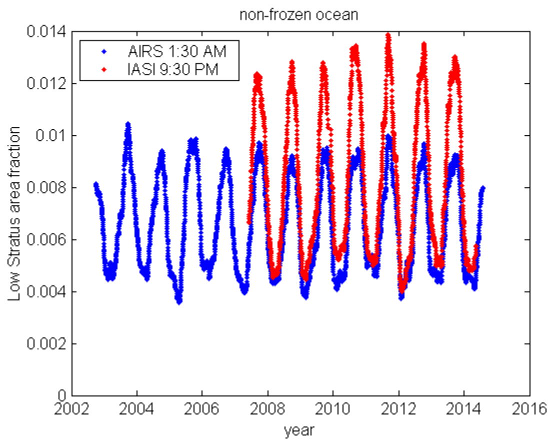
H. H. Aumann

The AIRS/IASI difference for low stratus are reasonably consistent with the diurnal cycle expected from tropical climatology.



Day ocean
AIRS 0.0023
IASI 0.0079

IASI more than AIRS: Consistent with diurnal cycle of marine layer

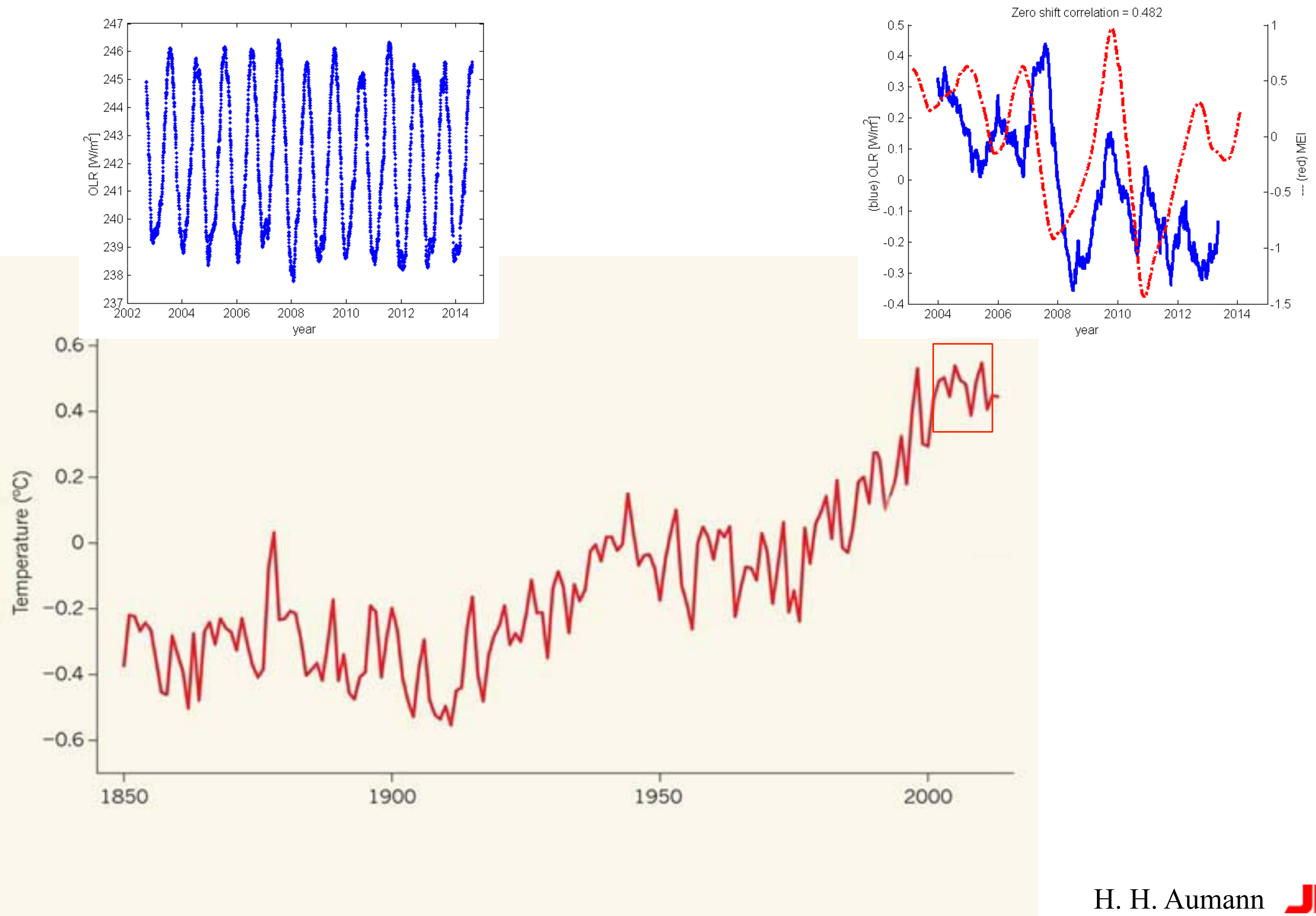


Night tropical ocean
AIRS 0.0066
IASI 0.0084

??

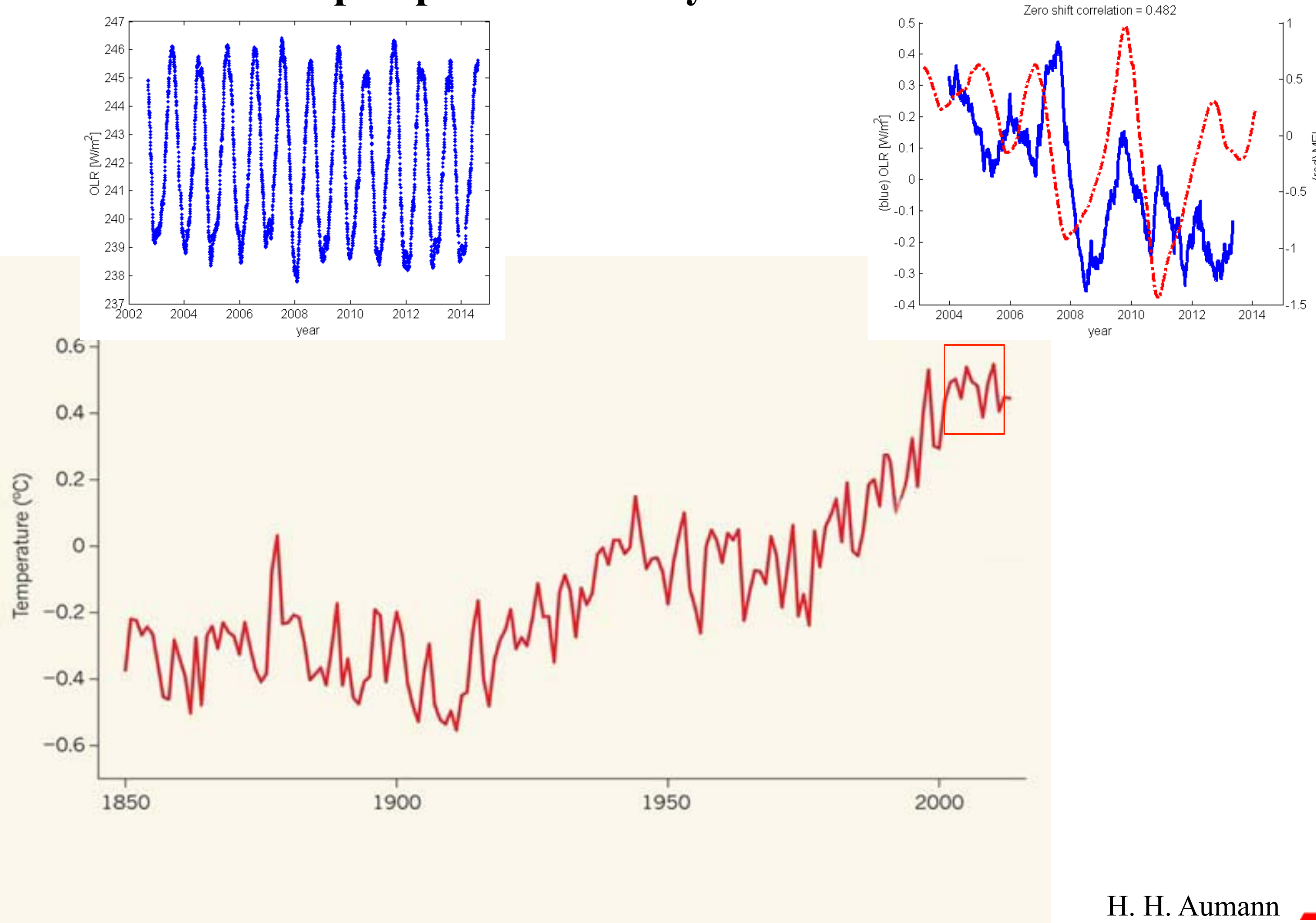
H. H. Aumann

All cloud related parameter (including OLR) show interannual variability suggestive of ENSO



H. H. Aumann

The observed interannual variability from 12 years is insignificant from the perspective of 150 years.



H. H. Aumann

3. Connection to Climate

The AIRS and IASI data define climate parameters.

The connection between climate parameters and climate change is through climate models.

3. Connection to Climate

The AIRS and IASI data define climate parameters.

The connection between climate parameters and climate change is through climate models.

Climate models have to match the observed climate parameters.

3. Climate Signals and Climate Models

We convert the state of the atmosphere and clouds defined by the climate models in the AR5 into infrared spectra and do the PDF time series analysis.

3. Climate Signals and Climate Models

We convert the state of the atmosphere and clouds defined by the climate models in the AR5 into infrared spectra and do the PDF time series analysis.

There are at least two algorithms (UMBC and NASA Langley) which combine radiative transfer and scattering code to convert the T(q), q(p) cloud property layers in the ECMWF and GMAO to AIRS L1B spectra.

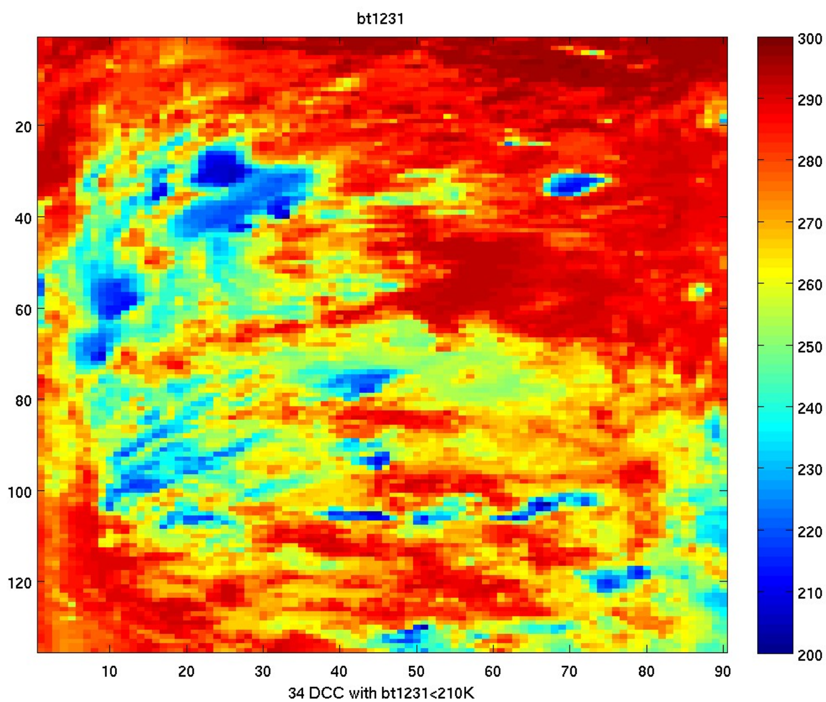
Details and validation of the UMBC algorithm are in a paper in review (Sergio Machado et al.)

The UMBC algorithm was used to simulate the AIRS spectrum at the time and location of each footprint for three days (2008/12/08, 2009/03/01 and 2011/7/11). The ECMWF ¼ degree gridded product was time and space interpolated.

Details are shown for the 2008/12/08 data.

Evaluation of a granule 20081208.63 (tropical land) shows a good representation of low or no clouds. None of the 32 DCC observed in the AIRS data are in the ECMWF data.

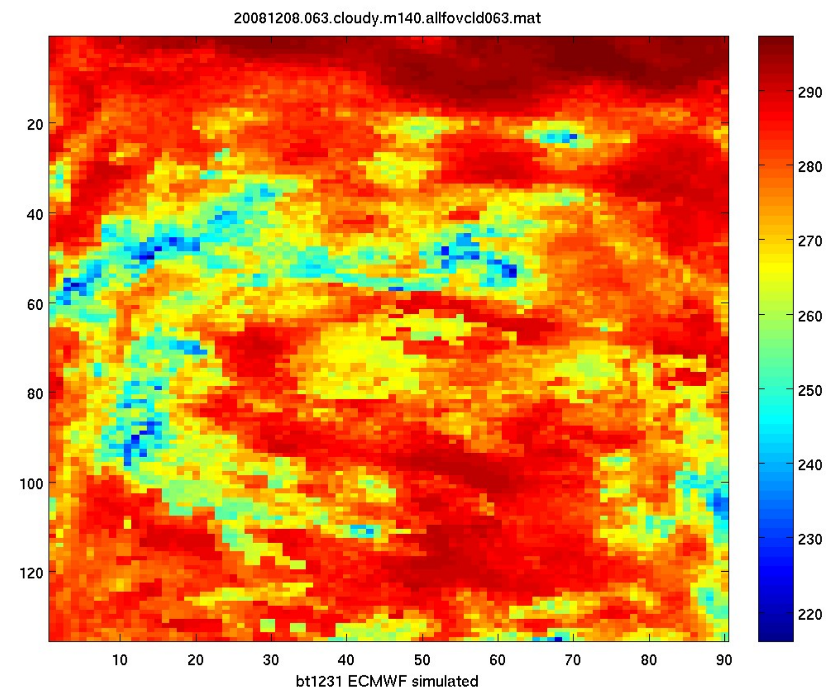
AIRS observed



abs((obs-calc)< 1K observed 350 of 12150

DCC observed 32

simulated using ECMWF



abs(obs-calc)<1K in the model 363 of 12500

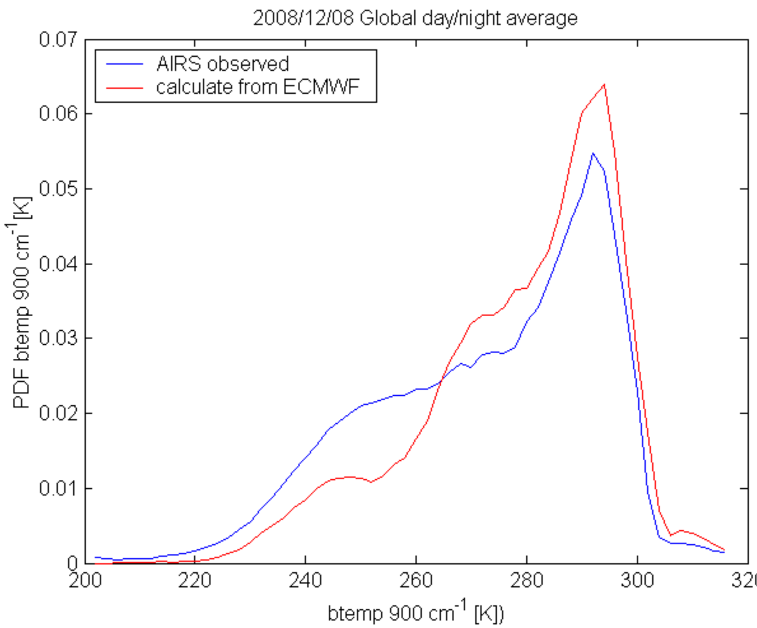
DCC in the model zero

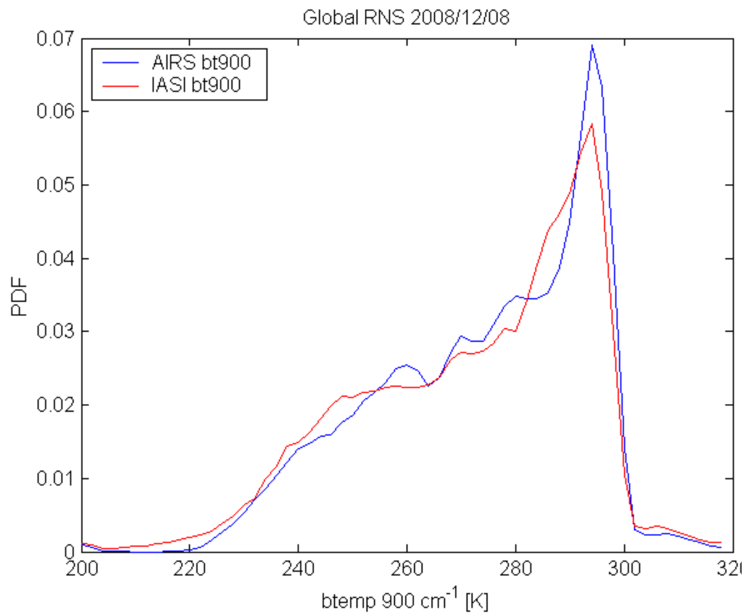
H. H. Aumann

Evaluation of all data from 20081208 shows

- **good representation of low or no clouds**
- **100s of km shift of major cloud patterns**
- **major under-representation of DCC**
- **Gross under-representation of low stratus**

- **The 900 cm-1 from AIRS and IASI at different time in the diurnal cycle agree better with each other than AIRS and the 2008/12/08 ECMWF model.**
- **The 2008/12/08 results are consistent with two other days (2009/03/01 and 2011/07/11)**





Work in progress:

We need to make the PDF time series for the ECMWF data and AR5 model data. Based on the 12 years of AIRS data, we don't need daily data to do the PDF analysis. 25 days from one year should suffice to define the seasonal signal

We have only given very simple examples of climate signals. Day/night differences, NH/SH differences at the AIRS and IASI overpass times, stratospheric temperature variation are also climate parameters which can be tested on models.

Some parameters, like OLR, are output from the climate models and can already be compared globally and NH/SH balance with AIRS. More on this in Ruzmaikin's talk.

Summary

- Climate is defined as the seasonally repetitive value of a weather related observable. Climate variability is derived from the analysis of the anomaly.

  Climate change is detected as significant deviations from the expected variability.

- AIRS and IASI data measure parameters related to climate and define variability on a decadal scale.
- Variability is large and dominated by ENSO events

  No climate change can be deduced from 12 years of data for clouds.

Summary

- Climate is defined as the seasonally repetitive value of a weather related observable. Climate variability is derived from the analysis of the anomaly.

  Climate change is detected as significant deviations from the expected variability.

- AIRS and IASI data measure parameters related to climate and define variability on a decadal scale.
- Variability is large and (currently?) dominated by ENSO events

  No climate change can be deduced from 12 years of data for clouds.

- The statistically correct representation of clouds in GCM and climate models is critical to the local and global feedback and energy balance

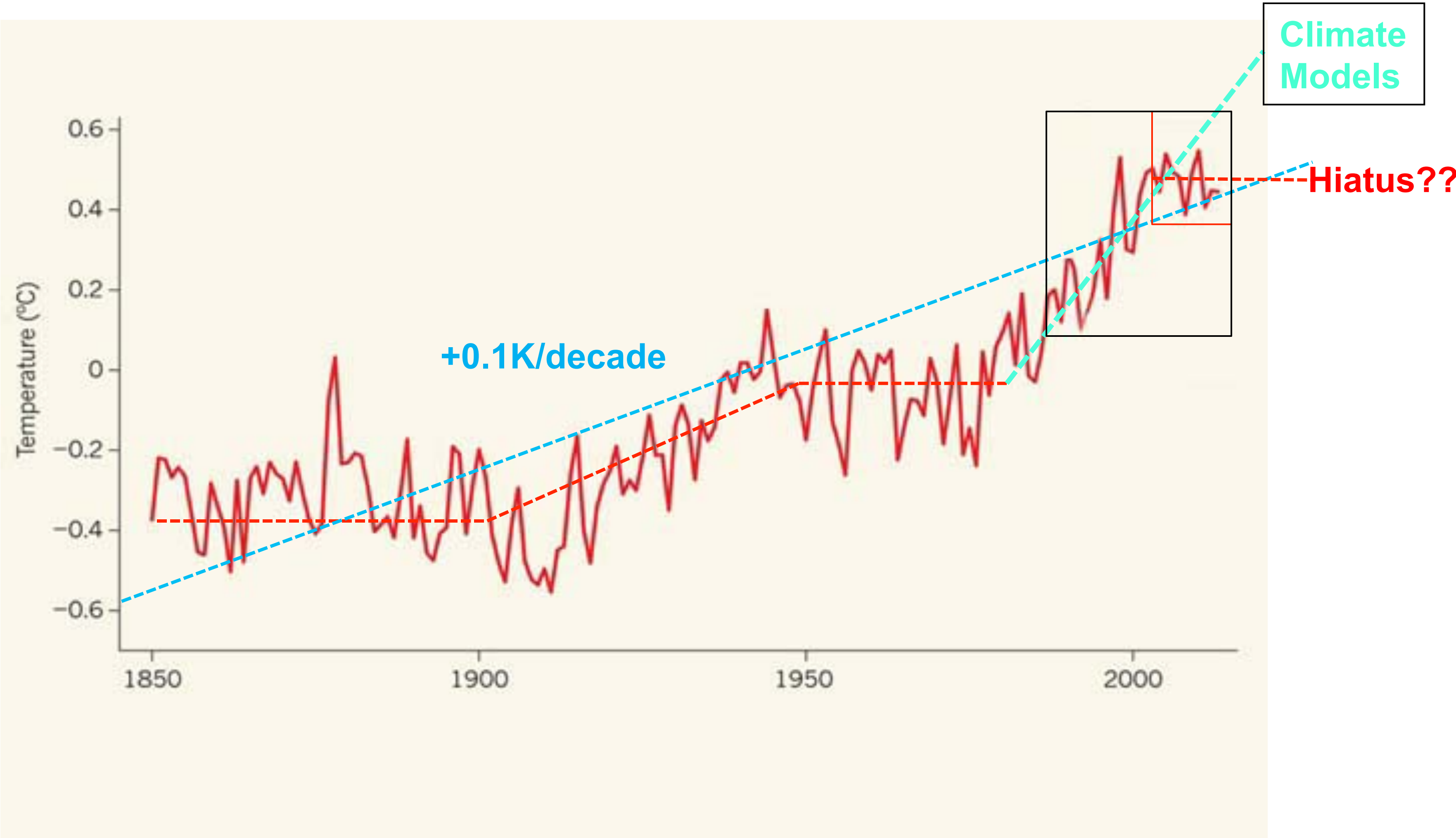
  Deep convective clouds and alto-stratus clouds are under-represented in the ECMWF model. The analysis of one year of data is planned.

  Other parameters, e.g. NH/SH day/night differences will be evaluated.

  Evaluation of AR5 models for clouds using the PDF analysis is funded for 2015.

H. H. Aumann

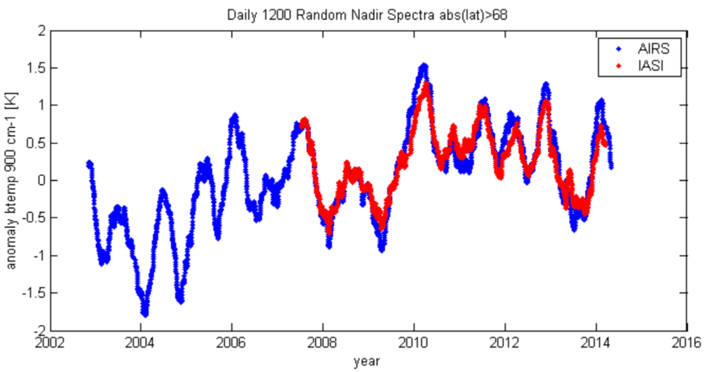
Changes in Climate Parameters deduced from 30 years of HIRS, 12 years of AIRS or 7 years of IASI have to be interpreted from the perspective of multi-decadal and longer variability.



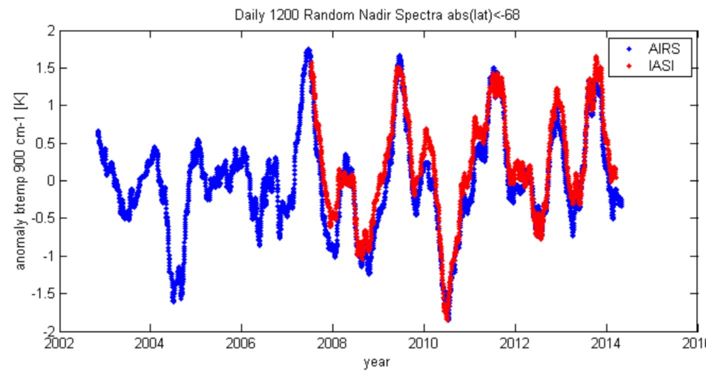
Time for questions

AIRS and IASI measure equivalent climate parameters at the same time and create similar anomalies

Anomaly for the arctic surface temperature



Anomaly for the antarctic surface temperature



A fast warming trend of the surface temperatures in the Arctic leveled off by the time IASI data became available.

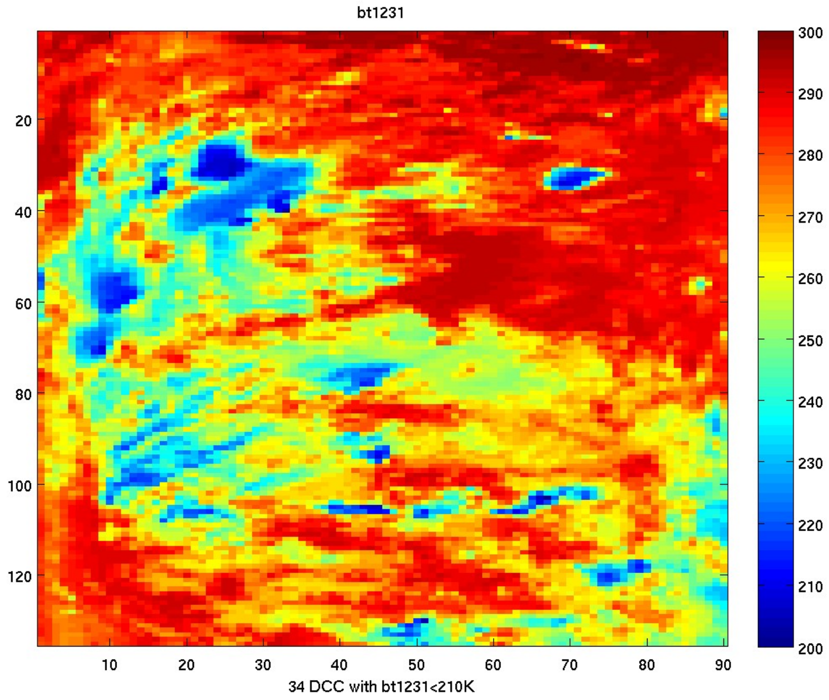
In the Antarctic we see consistent anomaly patterns, but no trend.

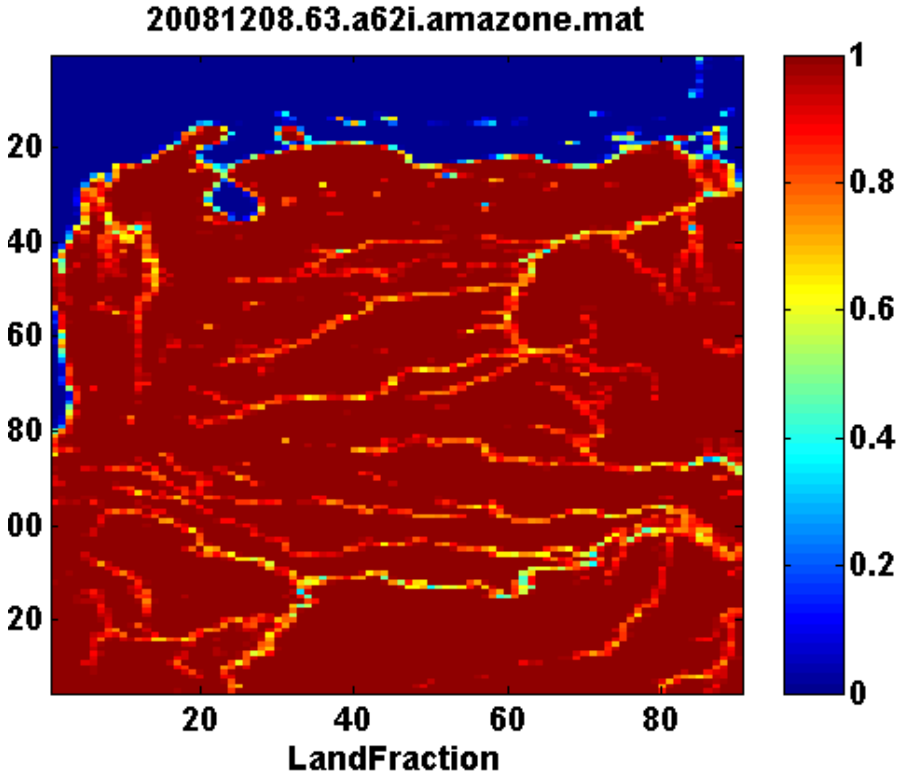
3K peak-to-peak inter-annual variability in the polar regions limits the interpretation of 12 year trends

H. H. Aumann

Evaluation of a granule 20081208.63

AIRS Observed





H. H. Aumann

Low or no cloud fraction in ECMWF 2008/12/08 data has the correct statistical flavor, alto stratus under-represented

Low or no clouds is the fraction of the spectra where abs(obs-calc) for the 1231cm-1 surface channel is less than 2 K.

	AIRS observed	2008/12/08 simulated
Day	0.39	0.40
Night	0.27	0.28

Alto Stratus (marine layer) are clouds which pass strict spatial coherence test virtually absent in 2008/12/08 ECMWF data

	AIRS Observed	2008/12/08 simulated
Day	0.00004	0
Night	0.023	0.00003

ECMWF marine layer clouds and AR5 model clouds are consistent with findings in

Axel Lauer, Kevin Hamilton, Yuqing Wang, Vaughan T. J. Phillips, and Ralf Bennartz, 2010: The Impact of Global Warming on Marine Boundary Layer Clouds over the Eastern Pacific—A Regional Model Study. *J. Climate*, 23, 5844–5863.

DCC are globally under-represented in the 2008/12/08 ECMWF data

		AIRS Observed	ECMWF calculated
Ocean	**Day Fraction**	**2.4%**	**0.48%**
	Night Fraction	**1.7%**	**0.41%**
Land	**Day Fraction**	**4.5%**	**1.13%**
	Night Fraction	**2.8%**	**0.30%**

The algorithm used by the scattering RTA for converting very high clouds in to radiances is very reliable.

DCC are typically in clusters larger than 100 km. This makes the AIRS/Model spatial resolution differences less important.

The discrepancies are real, not due to calculations.